Extreme Value Analysis of a Photodiode Circuit

An electrical component, such as a resistor or capacitor, is usually quantified with a nominal value and a tolerance. That is, a resistor could be rated at 5 with a tolerance of 5%; this means the resistance could vary between 4.75 and 5.25 .

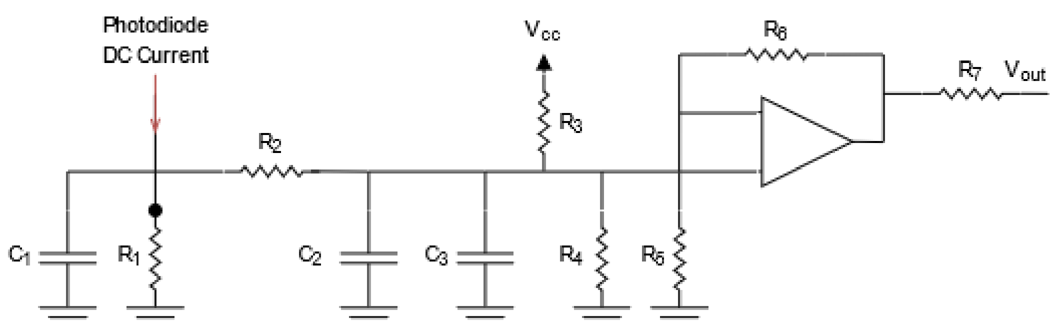
Given the number of components in a circuit and their compounded tolerances, the actual performance of a circuit may not necessarily match its desired performance. This is a source of risk that needs to be managed and mitigated.

Accordingly, electrical engineers need to analyze a circuit over all potential operating conditions.

Extreme Value Analysis (EVA) is a process in which the behavior of a circuit is simulated for every permutation of extreme component parameters - that is, a resistor of 5 ± 5% is simulated at 4.75 and 5.25 , in combination with every permutation of extreme values for all other components (this is a type of worst case circuit analysis).

Given the results of an EVA, a circuit that falls out of spec may have its performance improved by replacing cheaper components that have a loose tolerance with higher quality components that have a tighter tolerance.

This application performs an extreme value analysis of the following circuit (the principles, however, can be extended to any circuit). Light hits a photodiode and generates a current. A non-inverting op-amp then produces a linearly-proportional voltage from the photodiode current. Capacitors are ignored - hence this is a DC analysis.



Output voltage $$V_{out} := \left(R_1, R_2, R_3, R_4, R_5, R_6, R, V_{cc}, P\right) \to \frac{\left(\left(P \cdot R \cdot R_3 + V_{cc}\right) \cdot R_1 + V_{cc} \cdot R_2\right) \cdot R_4 \cdot \left(R_5 + R_6\right)}{\left(R_1 \cdot \left(R_3 + R_4\right) + \left(R_2 + R_4\right) \cdot R_3 + R_2 \cdot R_4\right) \cdot R_5}$$

Parameter values and fraction tolerances in the order R_1, R_2, R_3, R_4, R_5, R_6, V_{CC}, P

$$Rv := \begin{bmatrix} 9000 & 0.02 \\ 67500 & 0.02 \\ 2050000 & 0.01 \\ 89200 & 0.015 \\ 90000 & 0.015 \\ 87000 & 0.005 \\ 1.02 & 0.07 \\ 3 & 0.01 \\ 4.8 \times 10^{-4} & 0.05 \end{bmatrix}$$

V is a vector that contains the calculated voltages for every permutation of extreme tolerance values (there are 2^9 = 512 combinations of the two extreme parameter values for each of the nine components in the circuit).

zeta := Vector(512, i 1+~subs(0 =−1, Bits:-Split(i, bits = 9)) ·~Rv[.., 2])

V := Vector(512, i V_{out}(seq(Rv[j, 1]·zeta[i][j], j = 1 ..9)))

Hence the worst case minimum and maximum voltages are

min(V) = 3.980

max(V) = 5.486